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Physico-mechanical characterization of *Abies alba* Miller wood from the Spanish Pyrenees using clear specimens

Caracterización físico-mecánica de la madera de Abies alba *Miller procedente del pirineo español mediante probetas libres de defectos*

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SUMMARY

This study provides up-to-date, representative values of the physical and mechanical properties of silver fir wood from the Spanish Pyrenees for comparison with other provenances and timber species. Tests were conducted with clear specimens obtained throughout the tree stem and properties were determined following the UNE standards of the corresponding tests.

The wood was found to be light (ρ = 0.48 g/cm^3), soft (H = 1.71 mm^{-1}) and moderately stable (v = 39.43%). Its bending strength (MOR = 78.70 N/mm^2) is low and its compressive strength (MCS = 44.88 N/mm^2) is average. Impact behaviour is average (K = 41.46 N/mm) and cleavage behaviour (C = 19.92 N/mm) is low, as are tangential and radial tension perpendicular to the grain (1.71 and 1.68 N/mm^2). The differences obtained in comparison with other provenances of this species may be the result of the location of the silver firs at the edge of their geographical distribution and thus the specific conditions of the site have a greater effect on the wood properties.

660-10

Keywords: Wood; physical properties; mechanical properties; silver fir; *Abies alba* Mill.

RESUMEN

El objetivo de esta investigación es proporcionar valores actualizados y representativos de las propiedades físicas y mecánicas de la madera de abeto del Pirineo español para permitir su comparación con otras procedencias y especies maderables. Los ensayos se realizaron a partir de probetas libres de defectos obtenidas a lo largo del fuste y se determinaron las propiedades de acuerdo a las normas UNE de los ensayos correspondientes.

Se concluye que la madera es ligera (ρ = 0,48 g/cm^3), blanda (H = 1,71 mm^{-1}) y moderadamente nerviosa (v = 39,43%). La resistencia a flexión (MOR = 78,70 N/mm^2) es baja y a compresión (MCS = 44,88 N/mm^2) media. Presenta un comportamiento al impacto medio (K = 41,46 N/mm) y bajo a hienda (C = 19,92 N/mm), tracción perpendicular tangencial y radial (1,71 y 1,68 N/mm^2). Las diferencias obtenidas con respecto a otras procedencias de esta especie pueden deberse a que el abeto se encuentra en su límite de distribución geográfica y en consecuencia las condiciones específicas de sitio tienen mayor influencia en las propiedades de la madera.

Palabras clave*: Madera; propiedades físicas; propiedades mecánicas; abeto;* Abies alba *Mill.*

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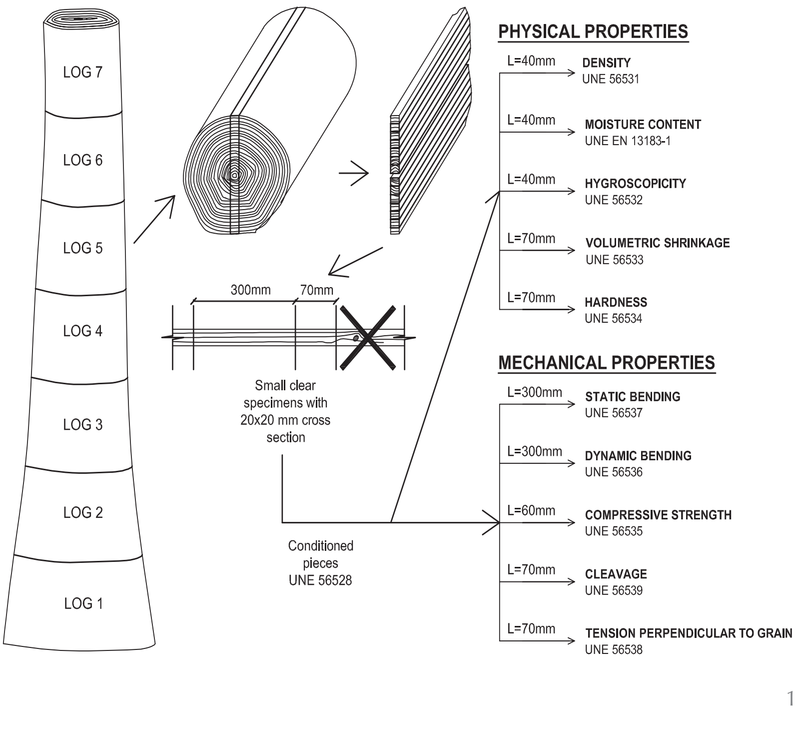
1. INTRODUCTION

Mechanical characterization of wood involves determining a series of properties associated with its structural behaviour. It may be conducted using either full-size pieces or small clear specimens (small, defect-free, oriented test pieces). The results of characterization with full-size pieces provide information about the real quality of timber currently on the market, but reveal little about the true potential of the wood, i.e., whether the silvicultural treatments and primary processing were ideal (1). Characterization with clear specimens makes it possible to determine the mechanical potential of wood and simulate behaviour in the presence of certain defects. Moreover, as this type of specimen was widely used in earlier studies, a comparison can be made of the results obtained from the wood of various species and provenances.

The silver fir (*Abies alba* Miller) occurs in central and southern Europe. Spanish silver fir forests are on the southeast edge of its area of distribution and are limited by the Mediterranean nature of the Iberian climate, particularly summer drought (2). Silver fir wood has traditionally been used as a construction material in the Spanish Pyrenees (3) and therefore the study of this wood is of particular interest for restoring and rehabilitating constructions in its area of distribution. The current protection level of forests of this species in the Iberian Peninsula has led to a decline in the use of silver fir timber.



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1. Diagram of the protocol followed for the physical and mechanical tests.

The mechanical properties of *Abies alba* have been little studied. The limited references dealing with the Iberian provenances of this species (4) (5) mostly correspond to general studies on the behaviour of a large number of species, with few specimens per provenance. Data on wood characteristics from various provenances must be available to determine quality and best uses due to the high variability in the physical and mechanical properties of wood, as the coefficients of variation can be as much as 30% (6).

This study determines the physical and mechanical properties of silver fir wood (*Abies alba*) from the Huescan Pyrenees (region of provenance the Midi-Pyrenees (7)) to provide up-to-date, representative values of: volumetric shrinkage (VS) and linear shrinkage, volumetric shrinkage coefficient (v), anisotropy, hygroscopicity (h), anhydrous density (ρ_0) and density at 12% moisture content (ρ), hardness (H), modulus of rupture in bending (MOR), longitudinal modulus of elasticity (MOE), maximum compressive strength parallel to grain (MCS), impact strength (K), cleavage (C) and tensile strength perpendicular to grain (TP).

2. MATERIAL AND METHODS

Specimens were taken from a mixed forest of *Abies alba*, *Pinus sylvestris* and *Fagus sylvatica* in the Huescan Pyrenees after selecting five trees representative of the forest. Trees were located at the foot of Mount Montinier, facing NE and E, on slopes less than 15% at altitudes of 1,165 to 1,182m above sea level. Samples were large enough for the physico-mechanical study to be representative of the species at this site (8) (9). Breast height diameter was greater than 30cm and with growth rings range between 80 and 92,tree stems were straight. Trees were in good phytosanitary condition, had no bifurcations and were not subject to edge effect.

Two-metre logs were cut from the stems and milled to produce 40mm planks. These were air dried to 18% moisture content and then machine cut into 35x35mm strips. The strips were conditioned to constant weight in a chamber at 20±2 °C and 65±5 % relative humidity and then the final clear specimens, with a cross section of 20x20mm, were prepared. The tests performed, specimen sizes and the standard used (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) are shown in Figure 1. After each test, the moisture content of the wood was calculated following the standard UNE-EN 13183-1 (12) to confirm conditioning.

A Microtest universal testing machine with two load cells of 5000 and 75000 N, class 1, was used for the mechanical tests and to determine hardness, although impact strength was determined with an Amsler universal testing machine. Physical tests were performed using a Sartorius A120S balance with a range of 0-120 g and 0.0001 g scale division, a Heraeus UT 6760 circulated air oven with a range of 0-300 °C and 1 °C scale division capable of maintaining a temperature of 103±2 °C, and a Mitutoyo Digimatic digital calliper with a range of 0-300 mm and 0.01 mm scale division. All equipment was calibrated and the uncertainties complied with the general requirements for the competence of technical and calibrating laboratories in the standard UNE-EN ISO/IEC 17025 (21) and the testing standards applied.

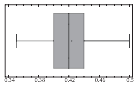
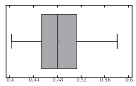
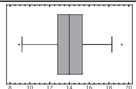
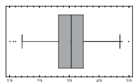
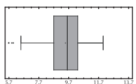
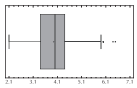
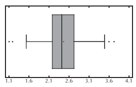
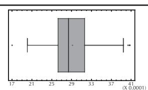
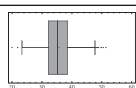
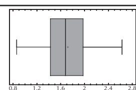
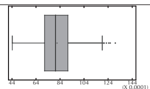
To determine the minimum number of specimens the sample should have for a significance level of 99%, the standard UNE 56528 (10) was used. A Grubbs' test was applied to the data obtained to remove outliers. All variables showing normality were identified. Statistical analysis was carried out with the Statgraphics Centurion XV.II calculation programme.

To determine the technological characteristics of the wood, the mean of the data obtained was interpreted with the assistance of the Standard UNE 56540 (22) and the interpretation proposed by Gutiérrez and Plaza (5) based on this standard.

3. RESULTS

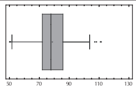
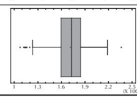
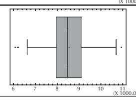
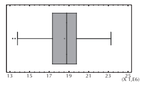
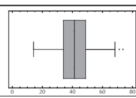
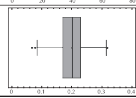
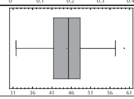
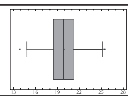
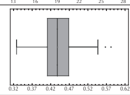
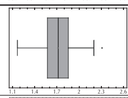
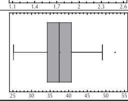
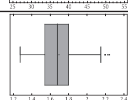
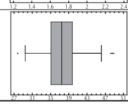
Tables 1 and 2 show the mean of the standard deviations obtained of the individual properties studied for each tree, as well as the standard deviation of each physico-mechanical value obtained. In Tables 3 and 4 the test results are interpreted using the Standard UNE 56540 (22) and the study by Gutiérrez and Plaza (5).

Table 1. Summary of the physical properties of A*bies alba* Mill wood from the Huescan Pyrenees

PHYSICAL PROPERTIES			**No. specimens tested**	**$\bar{x}$ / σ**	
Density	Anhydrous (ρ_0)	(g/cm³)	230	0.42/ 0.035 (S_N, C_N)	
	12% (ρ)	(g/cm³)	230	0.48/ 0.039 (S_N, C_N)	
Volumetric shrinkage (VS)		(%)	228	14.02/ 1.95 (S_N, C_N)	
Volumetric shrinkage coefficient (v)		(%)	228	39.43/ 7.28 (S_N, C_N)	
Linear shrinkage	Tangential (TS)	(%)	228	9.47/ 1.12 (C_N)	
	Radial (RS)	(%)	228	3.94/ 0.80 (C_N)	
Anisotropy (TS / RS)		( )	228	2.45/ 0.44 (S_N, C_N)	
Hygroscopicity (h)		(kg/mm³)	228	0.0029/ 0.0004 (S_N)	
Fibre saturation point (FSP)		(%)	225	35.69/ 5.50 (C_N)	
Hardness	Value (H)	(mm⁻¹)	365	1.71/ 0.40 (S_N, C_N)	
	Hardness strength (H/ ρ^2)	(m⁵/kg²)	365	$8.14x10^{-3}$/ $1.52x10^{-3}$ (C_N)	

(S_N) The standard error of the skewness is within the expected range for data from a normal distribution.
(C_N) The standard error of the kurtosis is within the expected range for data from a normal distribution.

Table 2. Summary of the mechanical properties of the wood of *Abies alba* Mill from the Huescan Pyrenees

MECHANICAL PROPERTIES				No. specimens tested	$\bar{x}$ / σ	
Static bending strength		Value (MOR)	(N/mm²)	355	78.70/10.85 (S_N, C_N)	
Static bending strength		Bending strength (MOR/ 100*ρ*)	(Nm/kg)	355	1,713.54/207.40	
Modulus of elasticity (long.)		Value (MOE)	(N/mm²)	349	8,504.11/872.00 (S_N, C_N)	
Modulus of elasticity (long.)		Modulus of elasticity (MOE/ *ρ*)	(Nm/kg)	349	$1.854x10^4/185.2x10^4$ (S_N, C_N)	
Impact strength		Value (K)	(N/mm)	334	41.46/10.75 (S_N, C_N)	
Impact strength		Dynamic strength (K/ ρ^2)	(Nm²/kg)	334	0.20/0.05 (S_N, C_N)	
Compressive strength		Value (MCS)	(N/mm²)	304	44.88/5.12 (S_N, C_N)	
Compressive strength		Toughness (MOR/MCS)	()	–	1.7	
Cleavage		Value (C)	(N/mm)	306	19.92/2.00 (S_N, C_N)	
Cleavage		Cleavability (C/100*ρ*)	(Nm²/kg)	306	0.44/0.04 (S_N, C_N)	
Tension ⊥ to grain	Tangential (TPt)	Value	(N/mm²)	134	1.71/0.22 (S_N, C_N)	
Tension ⊥ to grain	Tangential (TPt)	Bonding strength (TPt/ 100*ρ*)	(Nm/kg)	134	37.71/4.92 (S_N, C_N)	
Tension ⊥ to grain	Radial (TPr).	Value	(N/mm²)	130	1.68/0.19 (S_N, C_N)	
Tension ⊥ to grain	Radial (TPr).	Bonding strength (TPr/ 100*ρ*)	(Nm/kg)	130	37.34/3.76 (S_N, C_N)	

(S_N) The standard error of the skewness is within the expected range for data from a normal distribution.
(C_N) The standard error of the kurtosis is within the expected range for data from a normal distribution.

4. DISCUSSION AND CONCLUSIONS

The wood of *A. alba* from Mount Montinier is regarded as light and soft (Table 3). Volumetric shrinkage is average and the wood is moderately stable. At more than 2.2, its anisotropy makes it unsuitable for certain uses, due to its high tendency to distort. Its mechanical properties (Table 4) are, in general, low or average and its high ability to resist to severe impact is noteworthy.

Comparison of the data obtained for the physical properties and existing references on this species in the Iberian Peninsula show that silver fir wood from Mount Montinier (province of Huesca) has a density value 0.48 g/cm³ higher than average [0.42 g/cm³ (4)]. Gutiérrez and Plaza (5) obtained an average density of 0.44 g/cm³ for the silver fir populations in the province of Huesca. In France, the density obtained for this species (ρ = 0.46 g/cm³) in trees aged 32 years (23) was closer to the value in the present study.

Table 3. Interpretation following UNE 56540 (22) and Gutiérrez and Plaza (5) of the physical properties of *Abies alba* Mill wood from the Huescan Pyrenees

PHYSICAL PROPERTIES		INTERPRETATION OF RESULTS	
		Interpretation	Best use
Density at 12% (ρ)		Light	
Volumetric shrinkage (VS)		Average	Suitable for construction (average cracking)
Volumetric shrinkage coefficient (v)		Moderately stable	Suitable for construction
Anisotropy (TS / RS)		Marked tendency to distort	Not suitable for outdoor use
Hygroscopicity (h)		Normal	
Hardness (H)	Value (H)	Soft	Not suitable for carpentry or parquet
	Hardness strength (H/ ρ^2)	Normal; industrial timber	

Table 4. Interpretation following UNE 56540 (22) and Gutiérrez and Plaza (5) of the mechanical properties of *Abies alba* Mill wood from the Huescan Pyrenees

MECHANICAL PROPERTIES			INTERPRETATION OF RESULTS	
			Interpretation	Best use
Static bending strength		Value (MOR)	Low	
		Bending strength (MOR/ 100ρ)	Average timber for carpentry	
Modulus of elasticity (MOE/ ρ)			Stiff	
Impact strength		Value (K)	Average	
		Dynamic strength (K/ ρ^2)	Very strong	Timber capable of resisting severe impact
Compressive strength		Value (MCS)	Average	
		Toughness strength (MOR/MCS)	Low toughness	
Cleavage		Value (C)	Low	
		Cleavage strength (C/100ρ)	Low cleavability	Industrial timber or for special uses
Tension ⊥ to grain	Tangential (TPt).	Value	Low	
		Bonding strength (TPt/ 100ρ)	Average bonding	Timber for normal use
	Radial (TPr).	Value	Low	
		Bonding strength (TPr/ 100ρ)	Average bonding	Timber for normal use

The remaining physical properties are within the ranges proposed by the authors consulted, both for Spanish and French populations of the species (4) (24) (25) (26). The volumetric shrinkage coefficient (VS = 14.02%) is slightly lower than the value obtained by Gutiérrez and Plaza (5) (VS = 14.30%).

The wood of the Huescan Pyrenees silver fir shows differences in relation to the reference values of Spanish and French populations in terms of the mechanical properties. The bending strength value obtained by Gutiérrez and Plaza (5) for silver firs from the province of Huesca is more than 20% greater than for the population studied, whereas the wood of the French silver fir (27) shows 25% less bending strength than the value for the Mount Montinier silver firs. However, the wood studied shows a modulus of elasticity (MOE = 8,504.11 N/mm^2 ρ = 872.00) that is higher than the value determined for Spanish populations [MOE = 7,000 N/mm^2 (4)] and lower than the value for French populations [MOE = 10,515 N/mm^2 (27)].

The differences obtained in the physico-mechanical properties of this wood in comparison with earlier studies may be due to: a) the limited number of silver fir wood specimens tested in earlier studies in the Iberian Peninsula, considering the high local variability of the species; b) the location of the silver firs at the edge of their geographical distribution, meaning that the specific conditions of the site have a greater influence on the wood properties (2) (9).

Further studies on other populations of *Abies alba* from the Spanish Pyrenees will show whether the values of the physico-mechanical properties obtained can be extrapolated to all Spanish provenances or should be considered only for wood from the Huescan Pyrenees.

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